Alcator C-Mod 2007 PAC meeting highlights – M. Peng

Wednesday, January 24, 2006

13:00	Executive Session	Rich Groebner
13:15	Welcome and Charge	Miklos Porkolab
13:25	Comments from DoE	Adam Rosenberg
13:30	Program Overview	Earl Marmar
14:30	Lower Hybrid RF	Ron Parker
15:00	Cryopump	Brian LaBombard
15:20	Break	
15:30	Transport	Martin Greenwald
16:00	Macro-stability	Bob Granetz
16:30	Ion Cyclotron RF	Steve Wukitch
17:00	Executive Session	
19:30	Dinner (off-site)	

Thursday, January 25

8:30	Plasma Boundary	Bruce Lipschultz
9:00	Facilities and Diagnostics	Jim Irby
10:00	Theory and Modeling	Paul Bonoli
10:45	Break	
11:00	Integrated Scanarios: H-Mode Baseline	Steve Wolfe
11:30	Integrated Scenarios: Advanced Scenarios	Amanda Hubbard
12:00	Ideas Forum	Jerry Hughes
12:15	Run Planning	Steve Wolfe
12:30	Lunch (on-site)	
13:15	Tour	
14:00	Executive Session/Discussions with C-Mod team as desired	

Friday, January 26

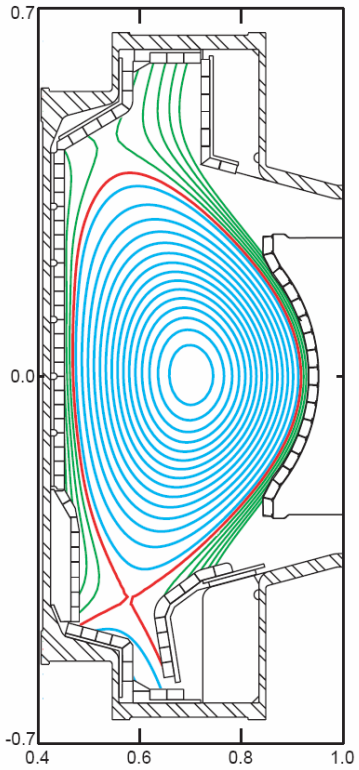
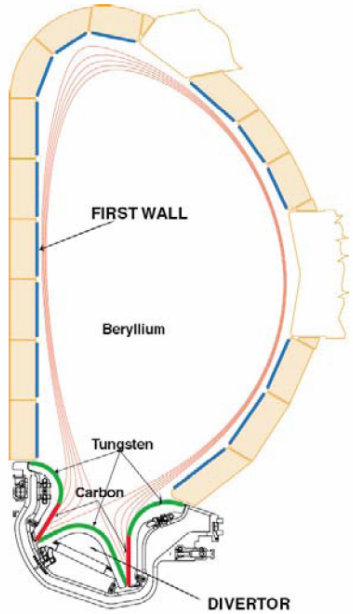
8:00	Executive Session - Draft response
11:00	Debriefing
12:00	Adjourn

- Rich Groebner, General Atomics (Chair)
- Chuck Kessel, PPPL
- Brian Lloyd, UKAEA, Culham
- Alberto Loarte, EFDA, Garching
- Dale Meade, PPPL (retired)
- Craig Petty, General Atomics
- Paul Terry, U. Wisconsin-Madison
- Jim Van Dam, U. Texas-Austin

- Adam Rosenberg, OFES (ex-officio)

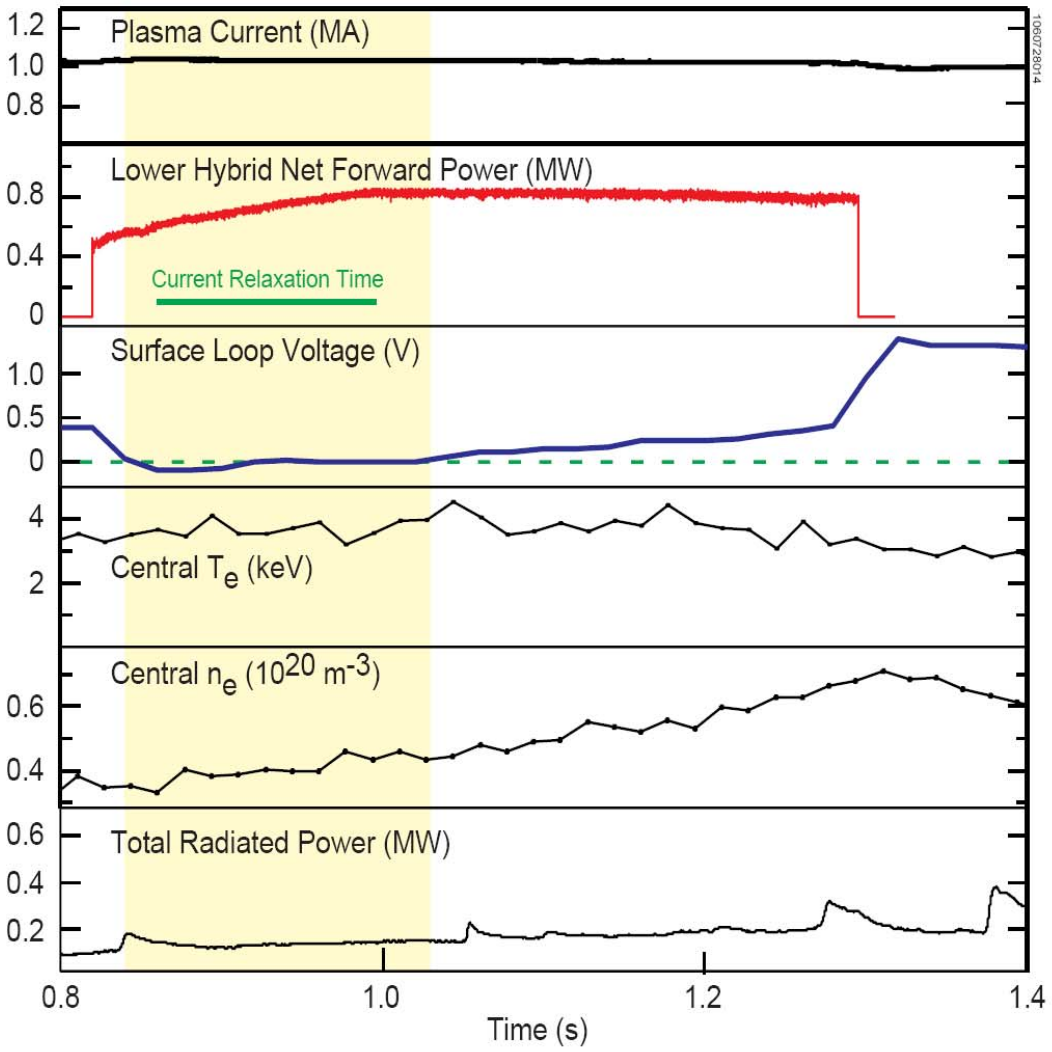
C-Mod program is directed to support ITER strongly

- Unique dimensional regimes
  - ITER B field, density, power density, plasma pressure
    - Disruption mitigation
    - Neutral opacity, Radiation Transport
  - High leverage database contributions
    - Dimensionally unique
    - Non-dimensional match to larger, lower field tokamaks
- ITER heating and current drive tools
  - Lower Hybrid Off-Axis CD
  - ICRF minority heating, MCCD
  - Torque and particle source free
    - Transport-driven rotation
- All-metal high-Z Plasma Facing Components
  - Molybdenum → Tungsten
    - Tritium retention, Impurity dynamics, Detachment
  - Wall conditioning; Low-Z wall coatings

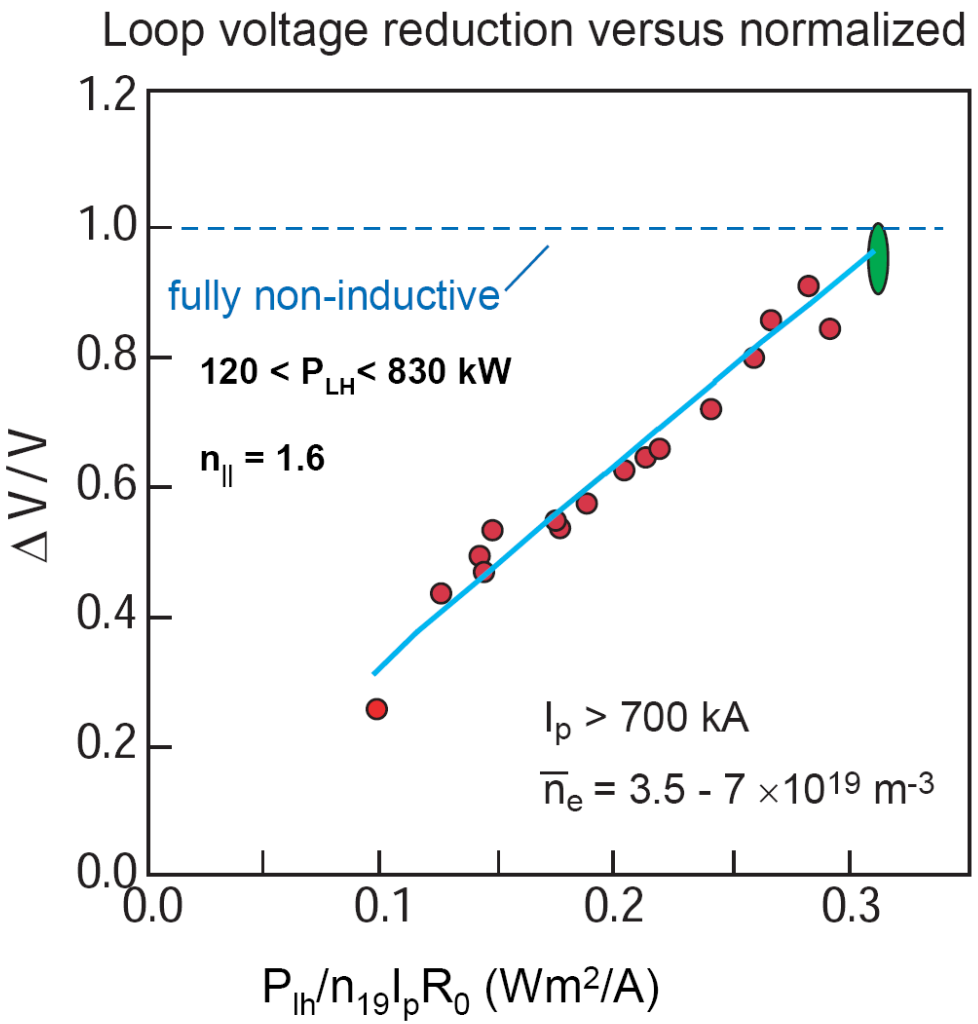
C-Mod	ITER/9
	
B_T = 5.3T, I_p = 1.6MA	**B_T = 5.3T, I_p = 15MA**
B ≤ 8.1 T, I ≤ 2.0 MA	
$\beta_N \leq 1.8$, $Z_{eff} \sim 1.5$	$\beta_N = 1.75$, $Z_{eff} < 1.6$
$0.1 \times 10^{20} < n_e < 10 \times 10^{20}$	$n_e = 1 \times 10^{20}$ m^{-3}
$P_{\|\|}$(SOL) ≤ 0.5 GW/m^2	$P_{\|\|}$(SOL) ≈ 1 GW/m^2

C-Mod made major progress in expanding operating scenarios using LHCD

- As shown in LH talk by Ron Parker, C-Mod exceeded target for 2006 campaign (which was 500 kW). Coupled > 900 kW.
- Also exceeded CD target; > 80% non-inductive (transient V_{loop}=0) at 1 MA. ('Phase I' target was 50% non-inductive).
- Implemented non-thermal diagnostics, extensive modeling of LHCD experiments, with generally good agreement; Further work is in progress.



Projections to fully NI plasmas suggests future upgrades to 4 MW for 1 MA.



Note: n_e = density @ T_e = 2.2 keV

Using method of Giruzzi[1]:

$I_p = I_{Ohmic} + I_{lh} + I_{hot}$

$I_{Ohmic} = V/R_{Ohmic}$

$I_{LH} = \eta_0 P_{lh}/n_{e19}R_0$

$I_{hot} = V/R_{hot}$

Fit: $y = (\eta_0 + \eta_1)x/(1 + \eta_1 x)$

$\eta_0 = n_{19}IR/P = 3.1 \pm 0.1$

$\eta_1 = 0.25 \pm 0.25$

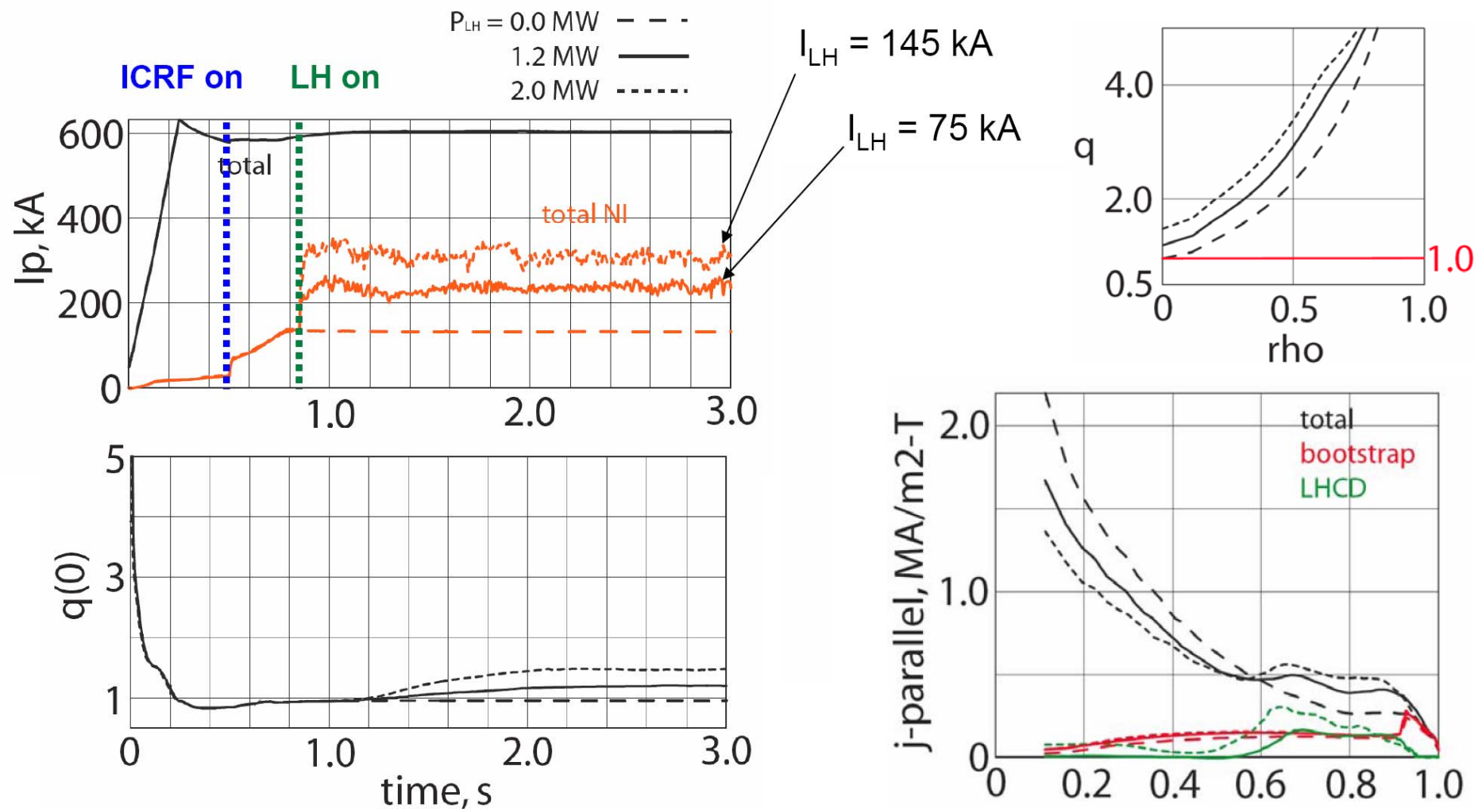
$= R_{Ohmic} n_e I_p R_0 / R_{hot} P_{lh}$

[1]**Giruzzi, G.,et.al.,Nuclear Fusion, 37 (1997) 673**

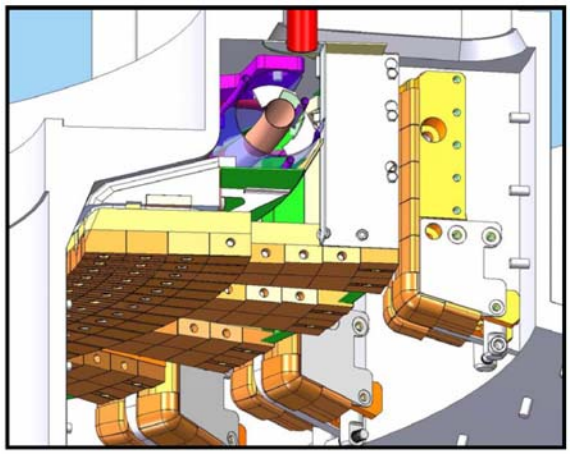
R. Wilson

Collaboration with TSC has been “a boom” to integrated scenario modeling of LHCD profile control

TSC couple with source terms from CQL3D and TRANSP

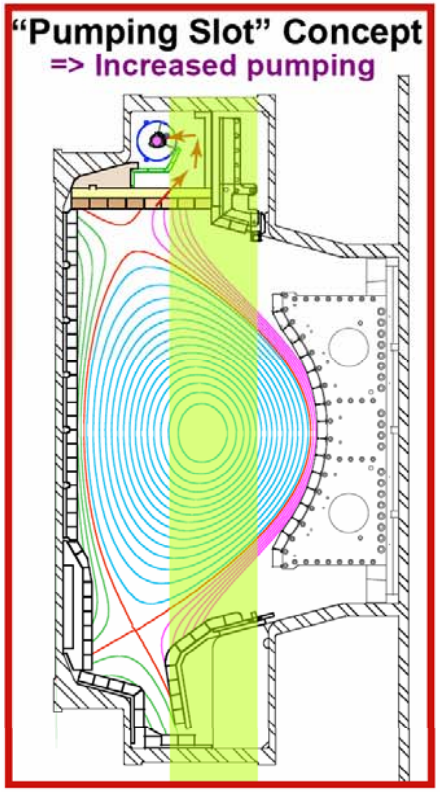


New cryo-pump is being installed and commissioned to support AT research



10,000 liters/s pumping speed (D_2)

'Duplicate' of C-Mod pump fully instrumented and tested off-line in a dedicated vacuum chamber

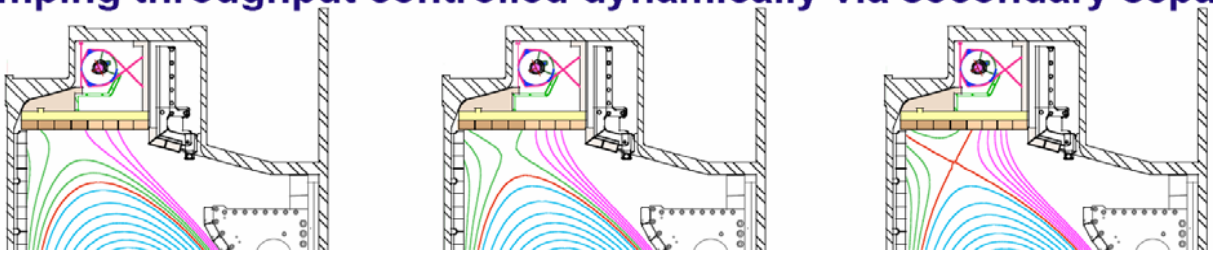


- Guided by experiments, design has evolved into a novel system of 30 'pumping slots'

- Pumping throughput insensitive to radial location of upper separatrix

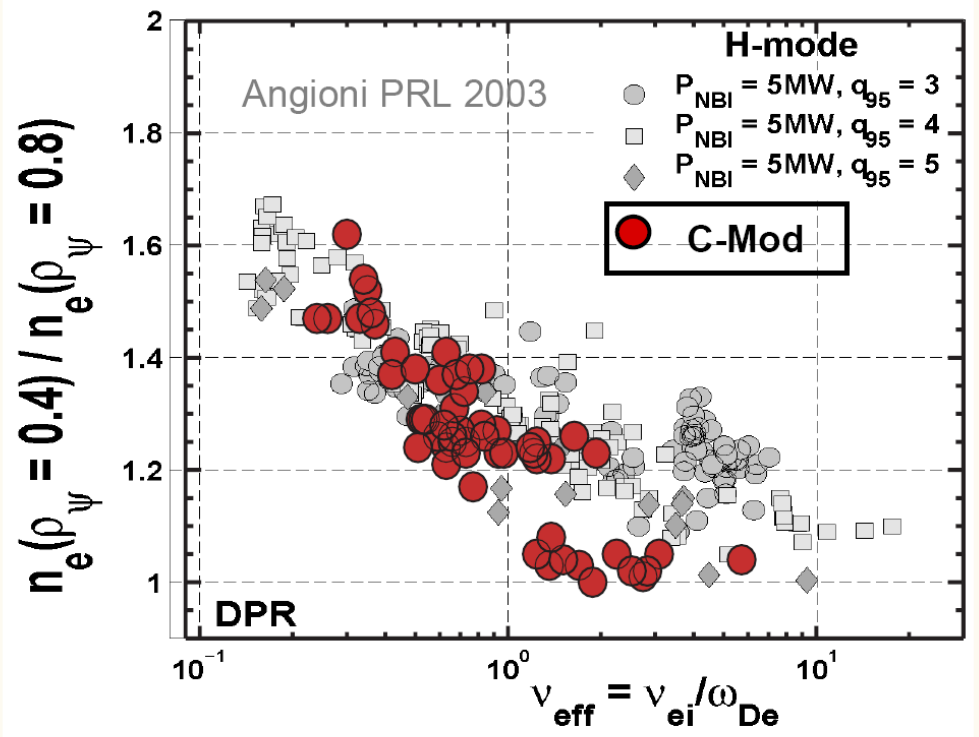
- Design accommodates vertical port laser access to R_{min}= 0.62 m (Thomson, TCI, PCI,...)

- Pumping throughput controlled dynamically via secondary separatrix



Test collisionality effects on particle transport & density profile with no particle source

- ITER Interest – better fusion performance with moderate density peaking
- Results from ASDEX, JET at low ν^*
- We've begun work on this (in a high-triangularity shape)
- High Priority Experiment: Exploit cryopump to broaden experimental base, scan ν^*, δ, q_{95} (ITPA CDB-9)
- Pedestal studies carried out at same time

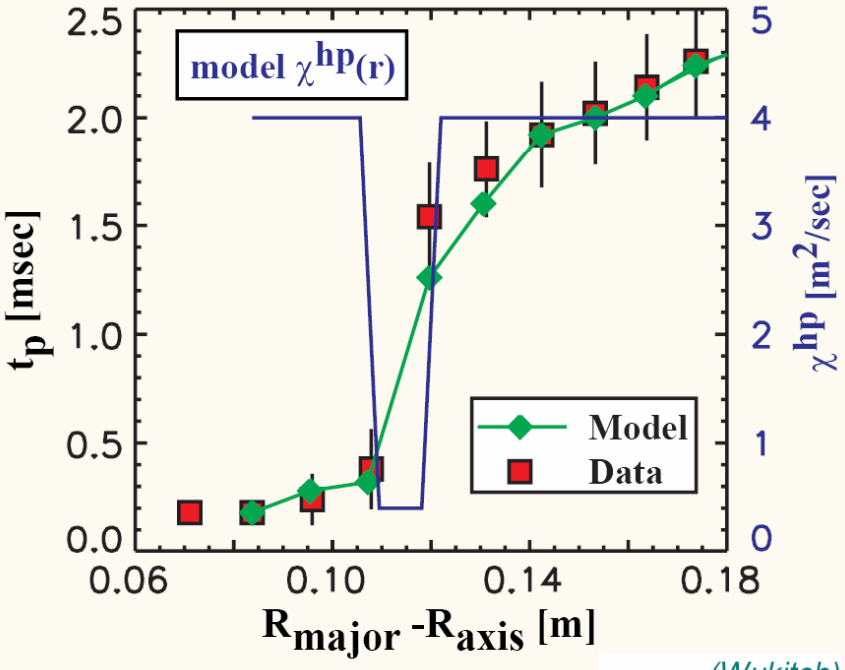


Addition of C-Mod data suggest that ν_{eff} is appropriate scaling variable rather than n/n_G (These are strongly correlated, especially on any given machine) – Good news for ITER

ITB research aims to verify model and correlate measured fluctuations with transport

- High Priority Expt: Verify model for barrier control via TEM turbulence using upgraded PCI measurements
- Barrier foot is a particularly interesting region
- High Priority Experiment: Measure fluctuations at foot of barrier
- Reflectometer
  - Correlation length measurements
  - 140GHz channel = 2.4×10^{20}
- Improved T_i profiles with HIREX III
- Background Experiments: Prepare ground for barrier experiments w/ modified shear

Heat pulse slows as it propagates through the barrier

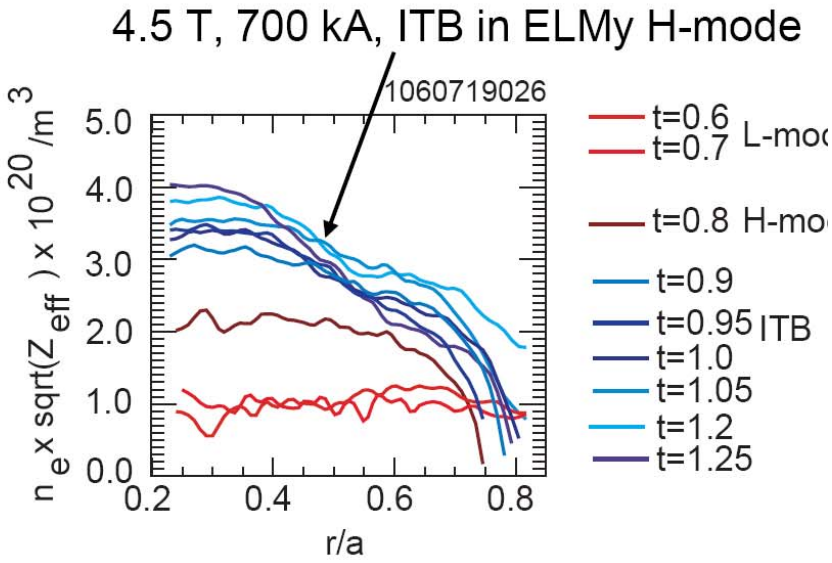


(Wukitch)

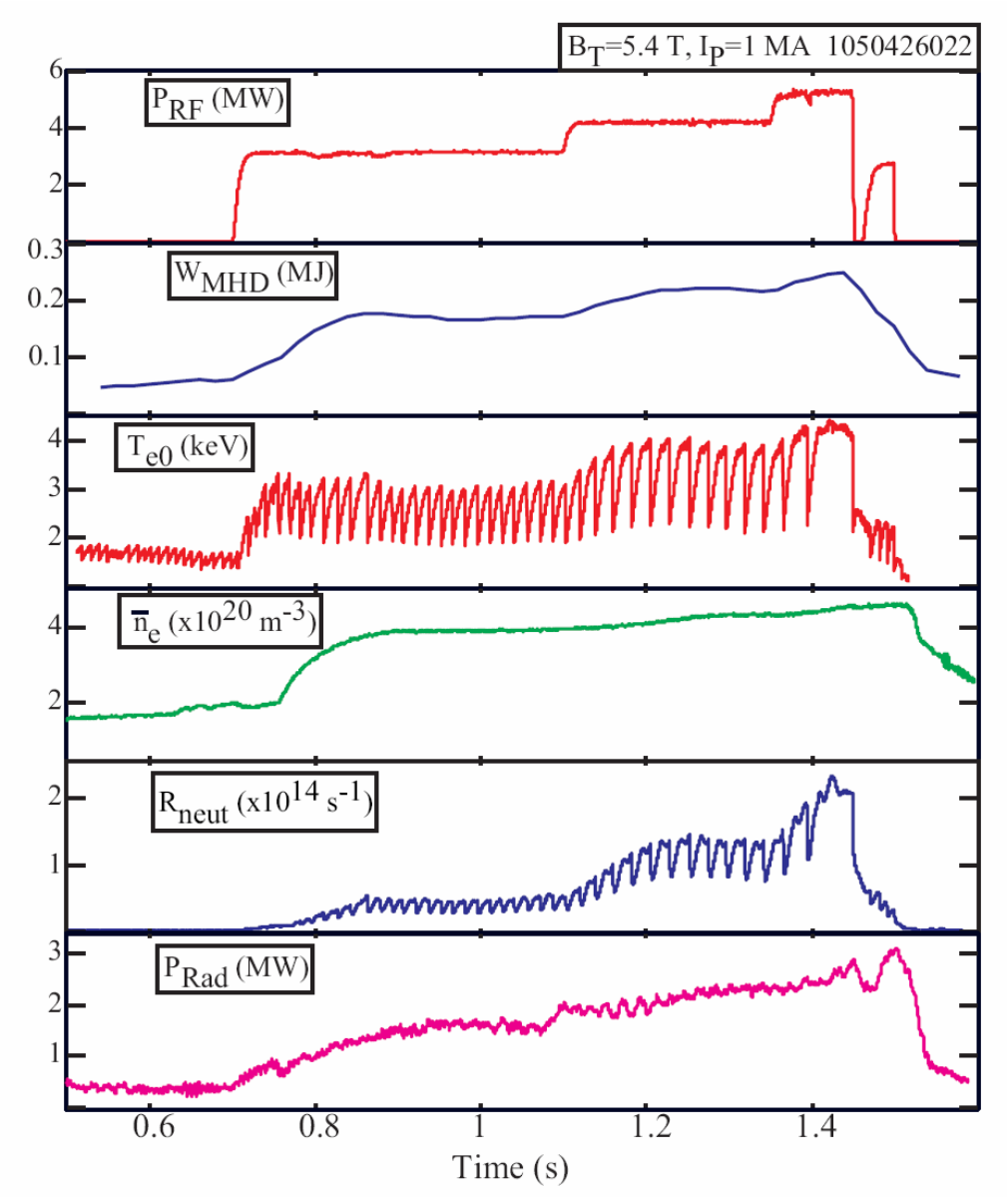
Transport barrier & control experiments will focus on effects of magnetic shear

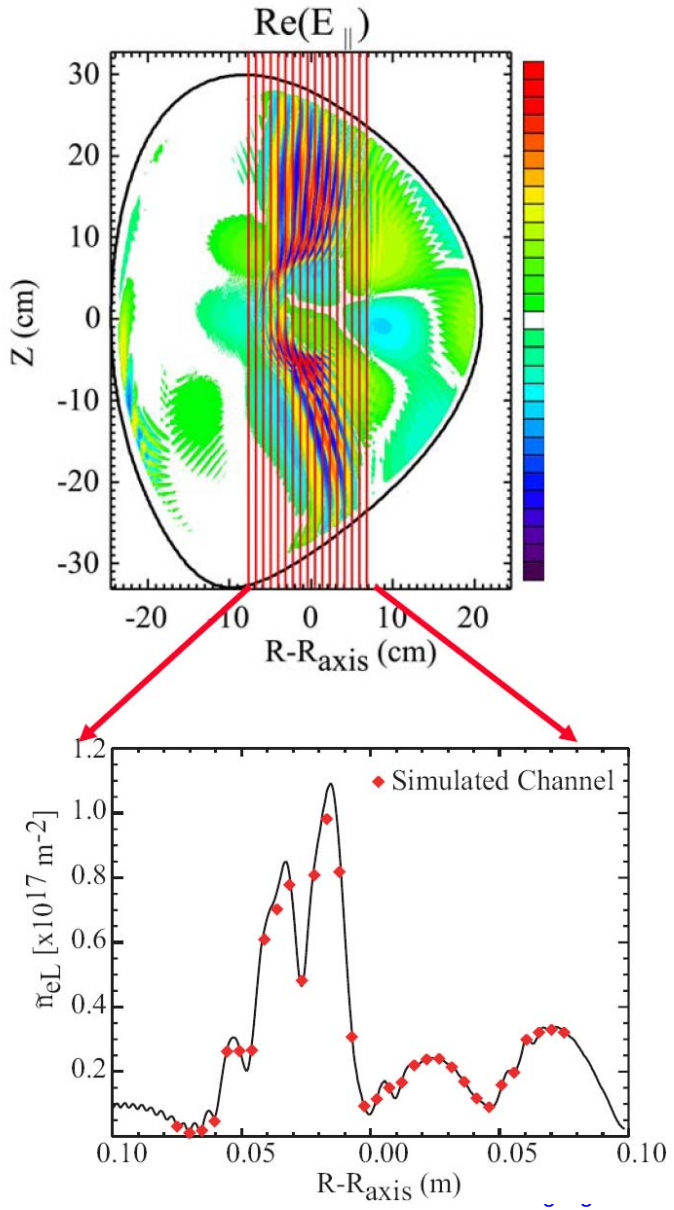
- To date, we have been studying ITBs with 'normal' shear – in contrast to most other experiments.
- Now that current profile control tool is available, we will focus on studying effects of *magnetic shear* on transport, ITB formation and properties.
  - **First step in 2007 will be to add LHCD to ITBs formed using off-axis ICRF.**
  - **How does shear change affect ITB threshold, and foot location?**
- In future phase, will study ITBs produced by **LH shear reversal**.
- All experiments will be in ITER-relevant regime with coupled electrons and ions, no momentum or particle input, pulse length > τ_{CR} *All of particular importance for ITBs.*

2007 experiments will use as LH target the low n_e ITBs being developed in the Transport topical area.



Core ICRF research is well prepared to compare measurement and theory





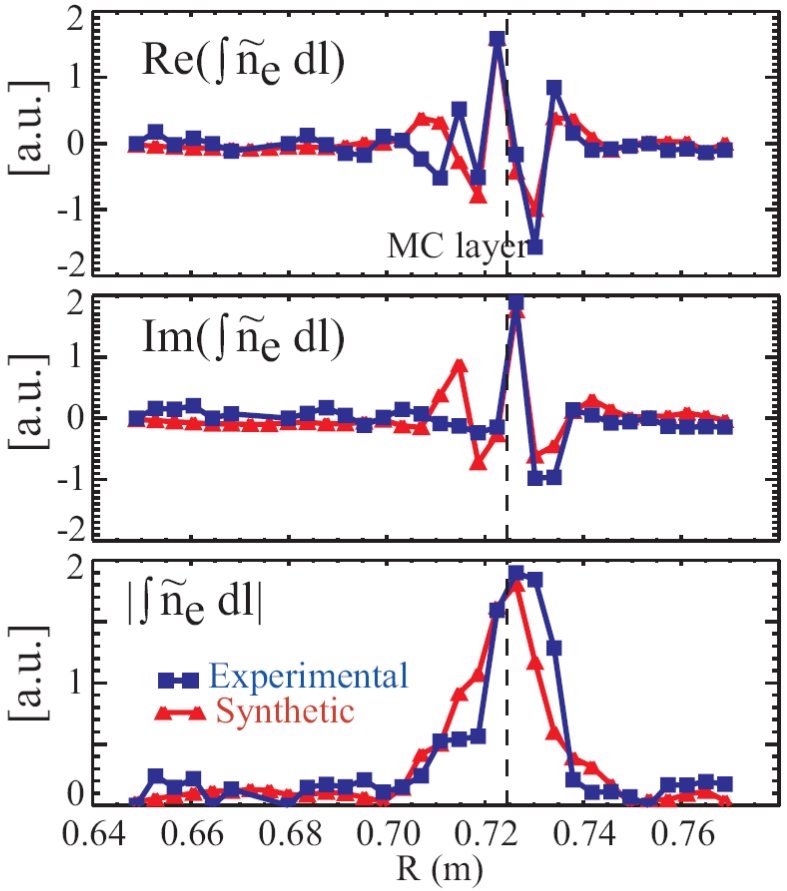
More detailed comparisons between measurement and theory are planned

Status:

- Synthetic PCI density fluctuation profile agrees with experiment.
- Improved absolute amplitude agreement after finding code renormalization problem.
- Implemented synthetic CNPA diagnostic and good agreement with Fokker-Planck simulation.

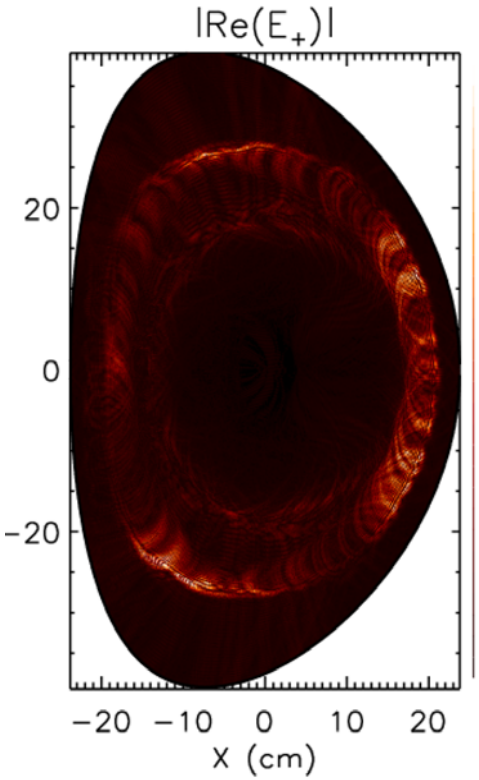
Plans:

- Implement improved absolute calibration of experimental data and compare with simulation amplitudes.
- Use CNPA to measure tail energy for second harmonic H scenario to test upgraded simulation capability.

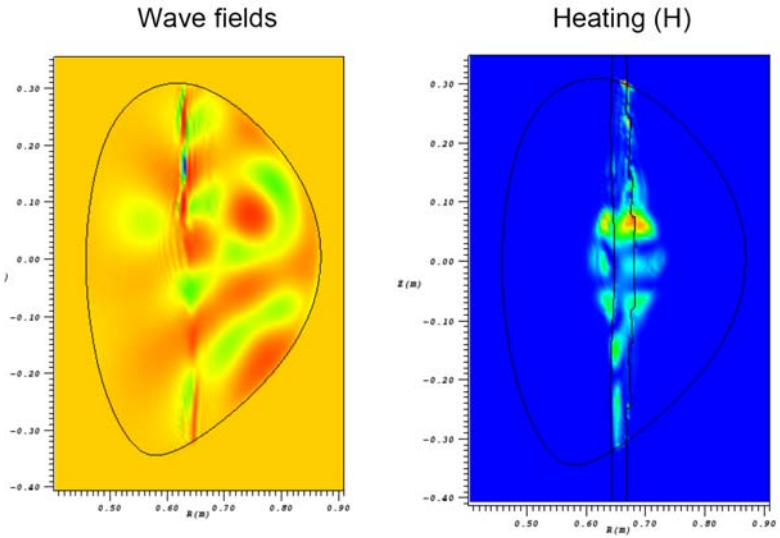


An array of numerical tools are brought to bear on the ICRF launcher and heating physics issues

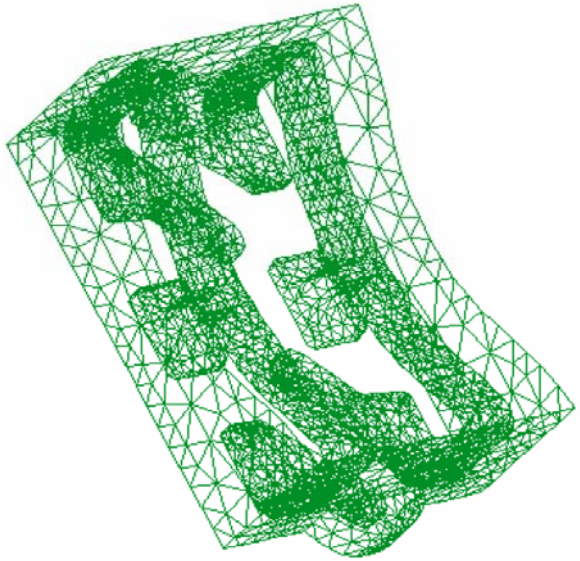
Full-Wave TORIC + CQL3D FP solver (1 hr @ 4096 cpus on CRAY XT3 JAGUAR)



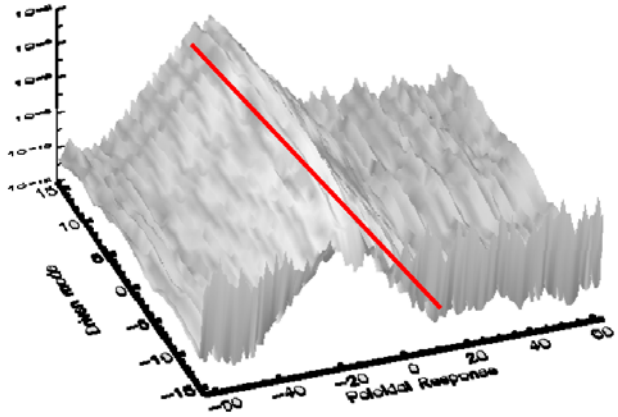
AROSA-CQL3D



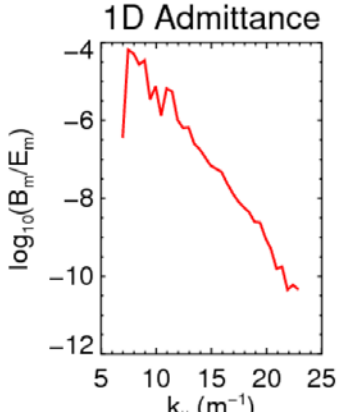
TOPICA – E antenna



$Y_{m,m'}$ TORIC Surface Admittance



1D response for m=[-16,16] plotted versus k||



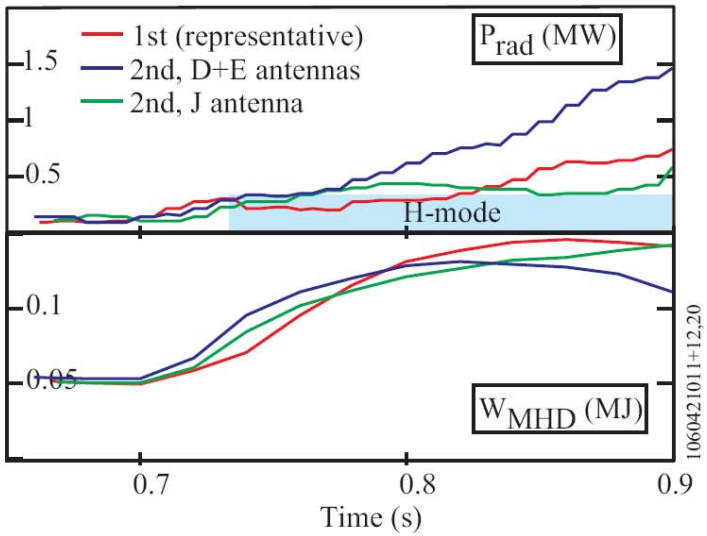
Antenna-edge boronization erosion and impurity production and deposition research is planned

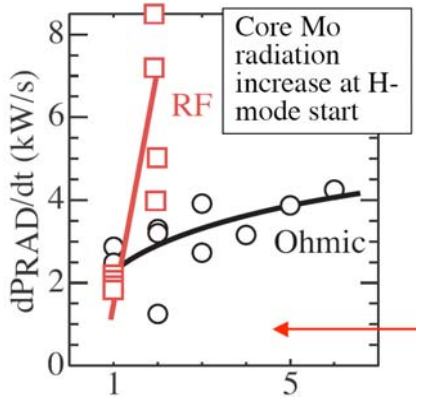
Status:

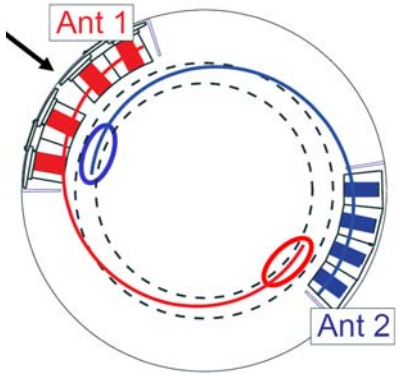
- Enhanced erosion/impurity production is localized to the active antenna.
- Identified outer divertor tiles as most important impurity source.
- Antenna characteristics dominate potential far-field effects.

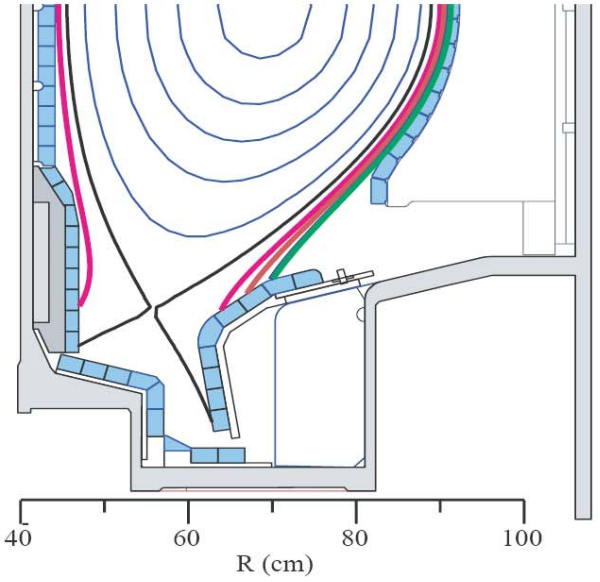
Plans:

- Installed marker tiles to further investigate localization and erosion rates.
- Assess what makes the shelf location the dominant core Mo contributor.

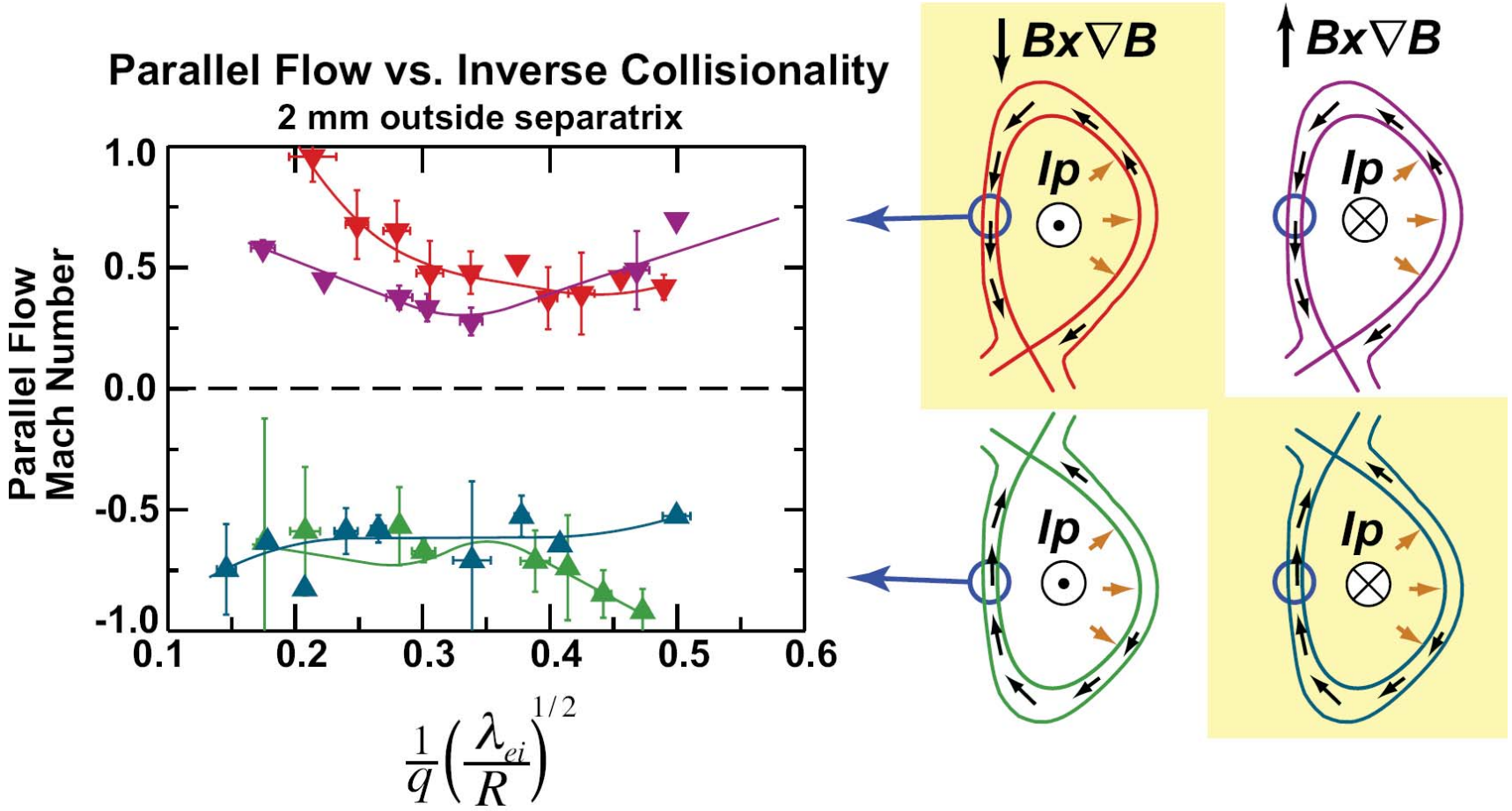








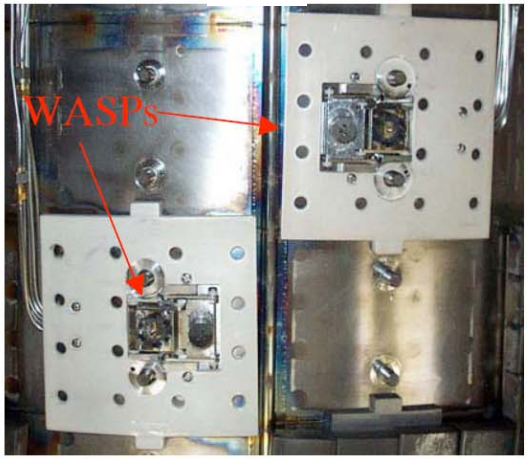
Near-sonic HFS parallel flows are driven by transport and depend primarily on x-point topology, not field direction



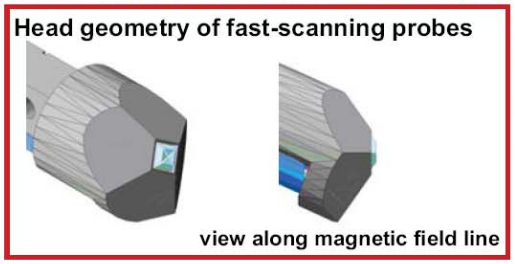
- Consistent with ballooning-like transport + X-pt location setting flow direction on high-field side
- 'Favorable' BxVB corresponds to co-current directed flow in SOL

Edge flows remains an important area of research through 2007

- New high-field side 'WASP' probes becoming operational - flows, fluctuation-induced transport,… **(PhD thesis topic)**
- New Mach probe heads on all three scanning probes: high-field, low-field side & vertical probes =>**better measure of ⊥ & ∥ flows**



High heat-flux, tungsten electrode geometry →



- CXRS measurements of boron and deuterium (high-field and low-field side views) will help assemble picture of flows across the separatrix **(PhD thesis topic)**

Key topics

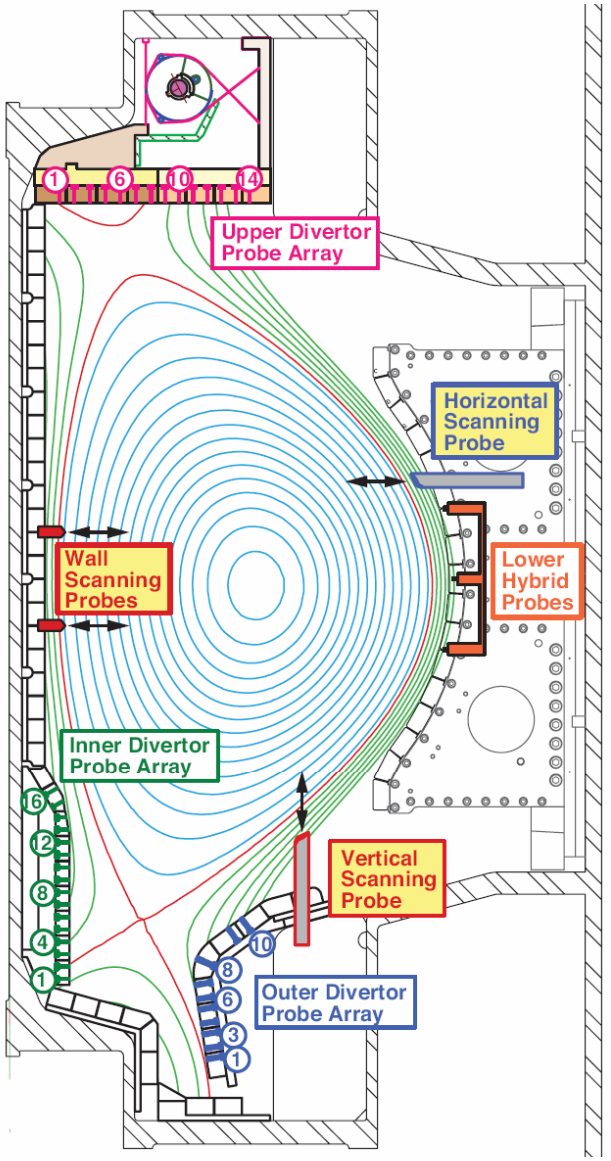
- Edge flow patterns at L-H transition and in H-mode
- What mechanism 'closes the flow loop' between high and low-field SOLs
  - inward ion pinch? - neutral recycling? Influence of detached divertor?

Theory & Modeling Contacts

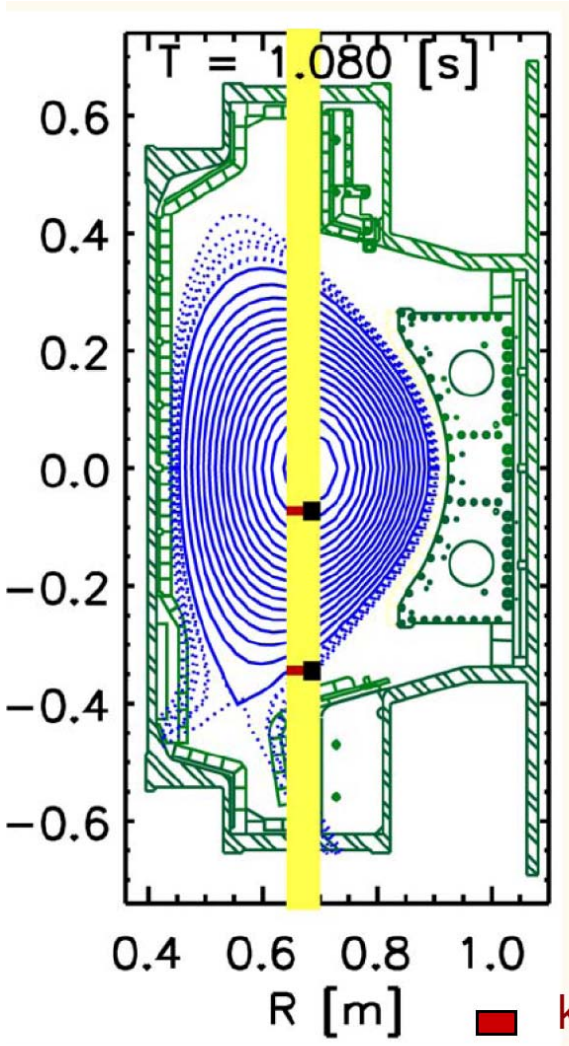
- A. Pigarov (UCSD) - comparison of observed and modeled flow patterns with UEDGE
- P. Catto (MIT) and A. Simakov (LANL) - exploit topological symmetries to analyze up-down symmetric and asymmetric contributions to flow field

Extensive array of probe diagnostic are being made available for boundary physics studies

- WASPs on high-field SOL **(PhD thesis topic)**
- New Langmuir probe array in Upper Divertor
  - Support of cryopump physics experiments
  - Opportunity for ELM studies at high triangularity
  - Useful SOL radial transport analysis and studying main-chamber recycling
- Prototype fast sweep I-V probe drive electronics to be tested on the Horizontal Scanning Probe
  - **PhD thesis topic**
  - Goal to simultaneously resolve fluctuations in 3 field quantities (T_e, n_e, Φ) at ~ 1 MHz
  - => more direct information on turbulent cross-field particle and heat fluxes than standard Langmuir probe sweeps



Diagnostic resolutions are being upgraded to enable electron energy and momentum transport studies



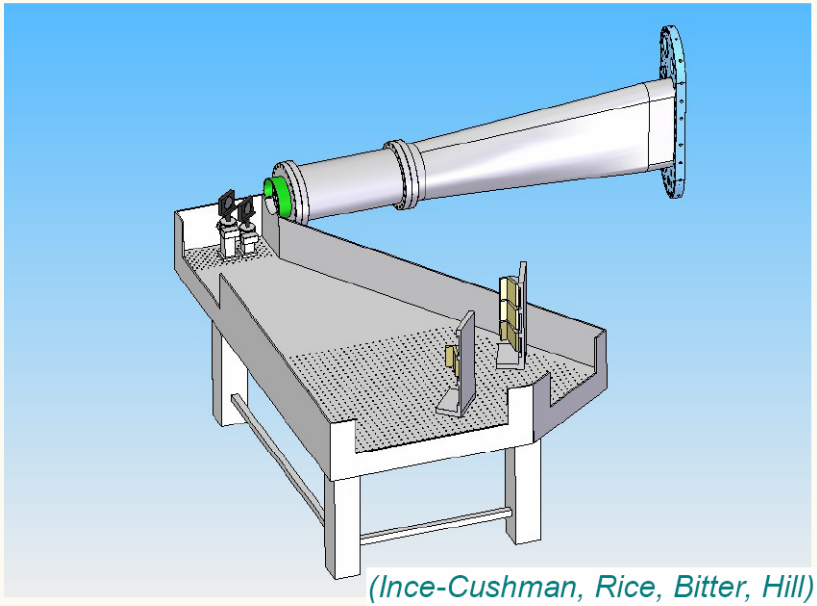
Phase Contrast Imaging

k_θ ~ 50 cm^{-1}

k_θ ~ 30 cm^{-1}

Major diagnostic initiative

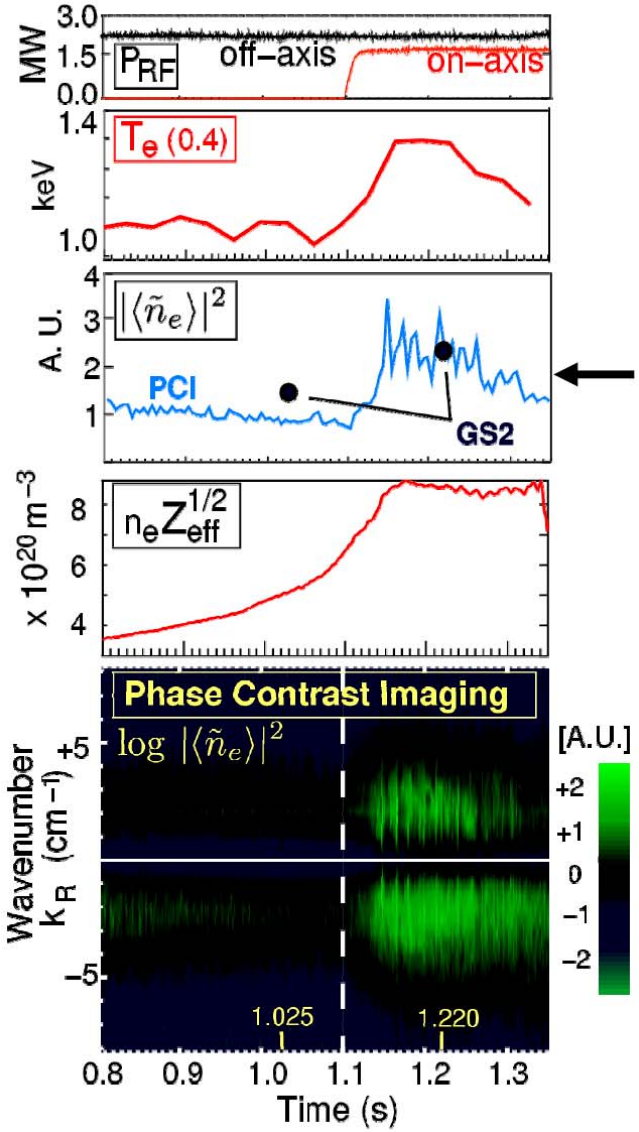
⇒ HIREX III + NeSox + CXRS



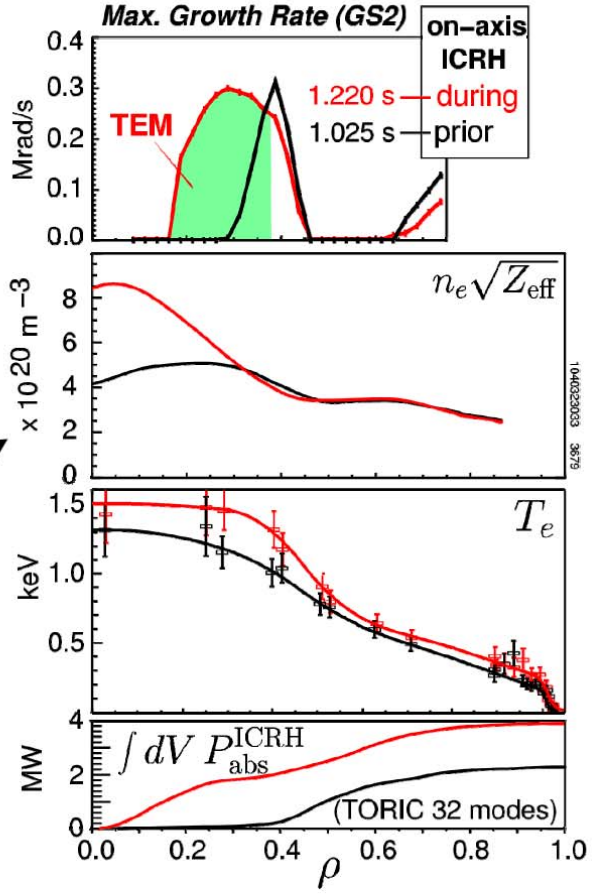
(Ince-Cushman, Rice, Bitter, Hill)

New high-resolution x-ray spectrometer (HIREX III) with increased radial coverage, resolution, time response (part of MIT/PPPL collaboration)

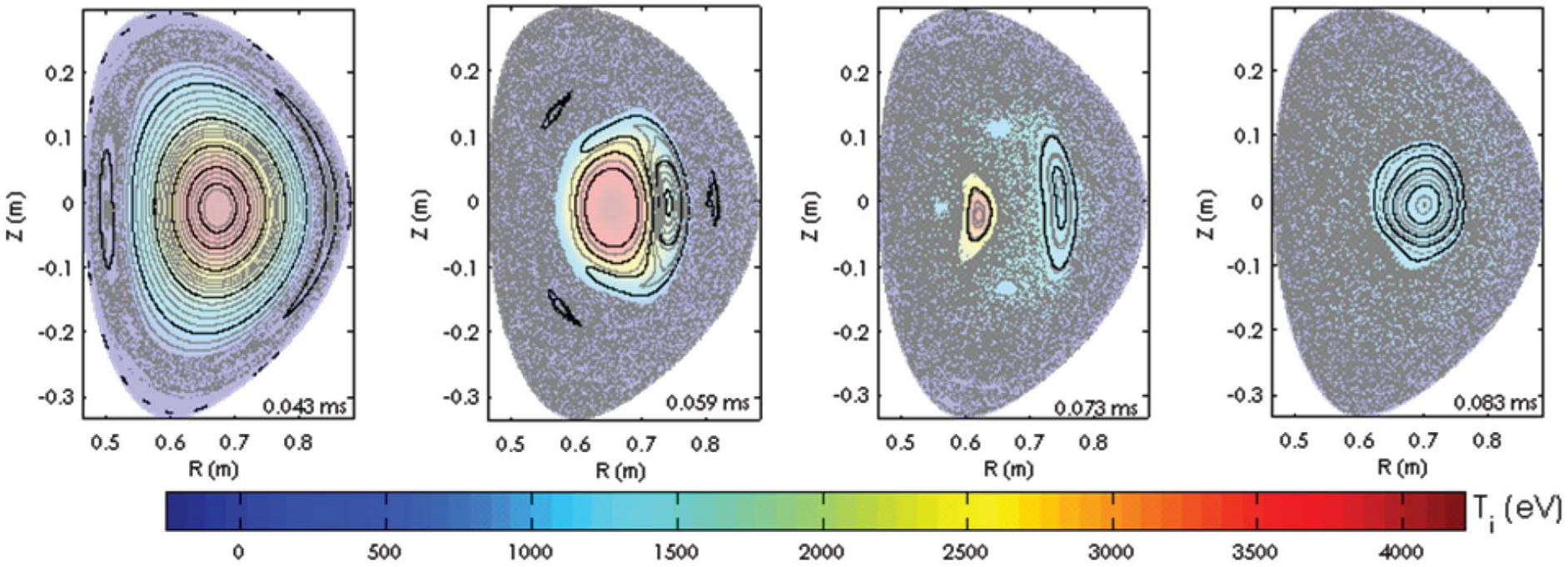
Trapped electron mode turbulence was identified in central ICRF heated plasmas



- PCI shows strong density fluctuations during on-axis heating of ITB
- Relative increase in fluctuation level reproduced by nonlinear GS2 simulations
- Linear stability analysis shows TEM dominates PCI spectrum during on-axis heating (ITG in barrier prior to on-axis ICRH)

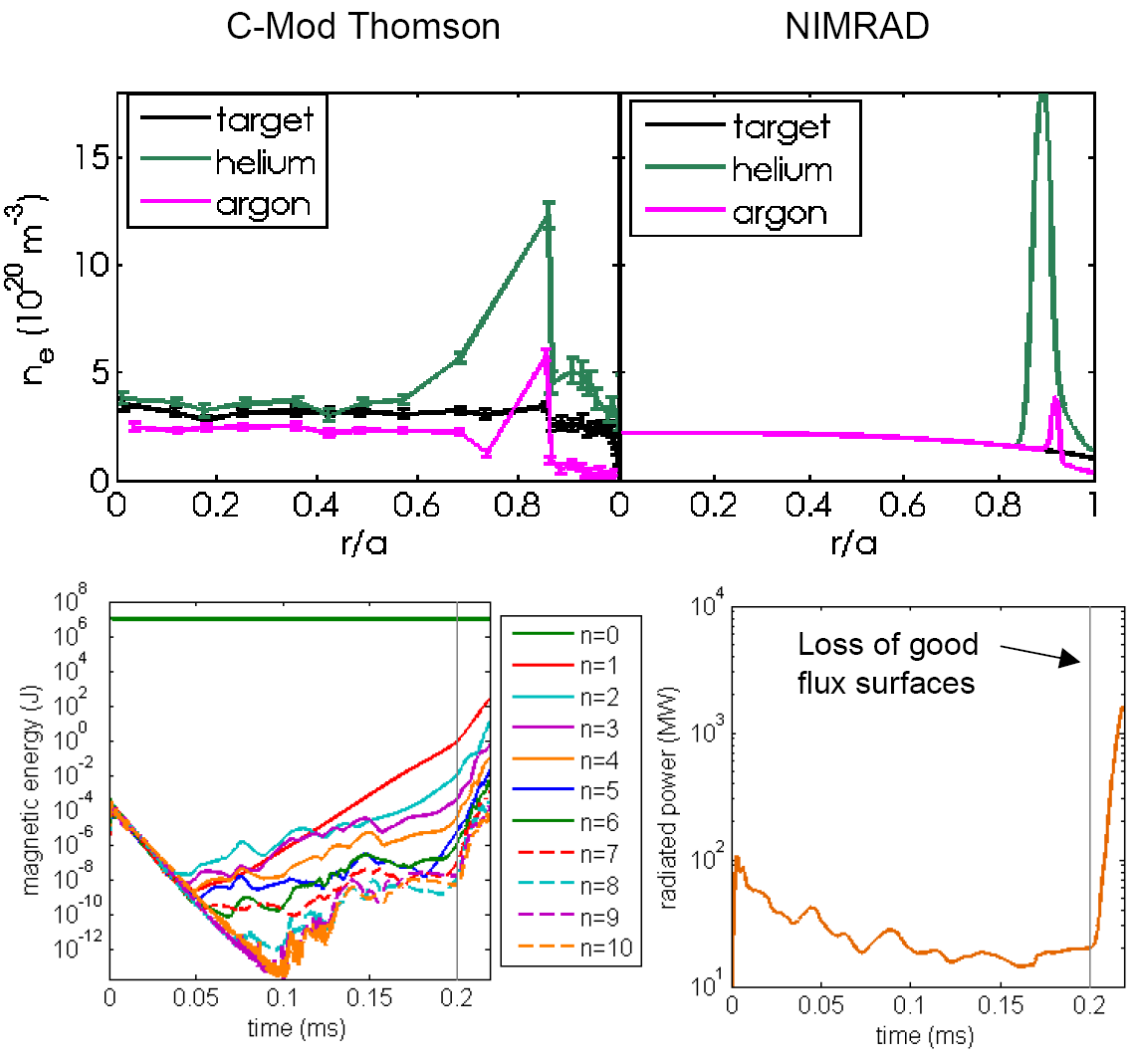


NIMROD simulations of Gas-Jet mitigation experiments show that equilibrium edge is rapidly cooled



- 2/1 mode appears first and stochastic fields form at the edge, eventually destroying all field lines outside q=1
- 1/1 mode levels core temperature by swapping cold island with hot magnetic axis

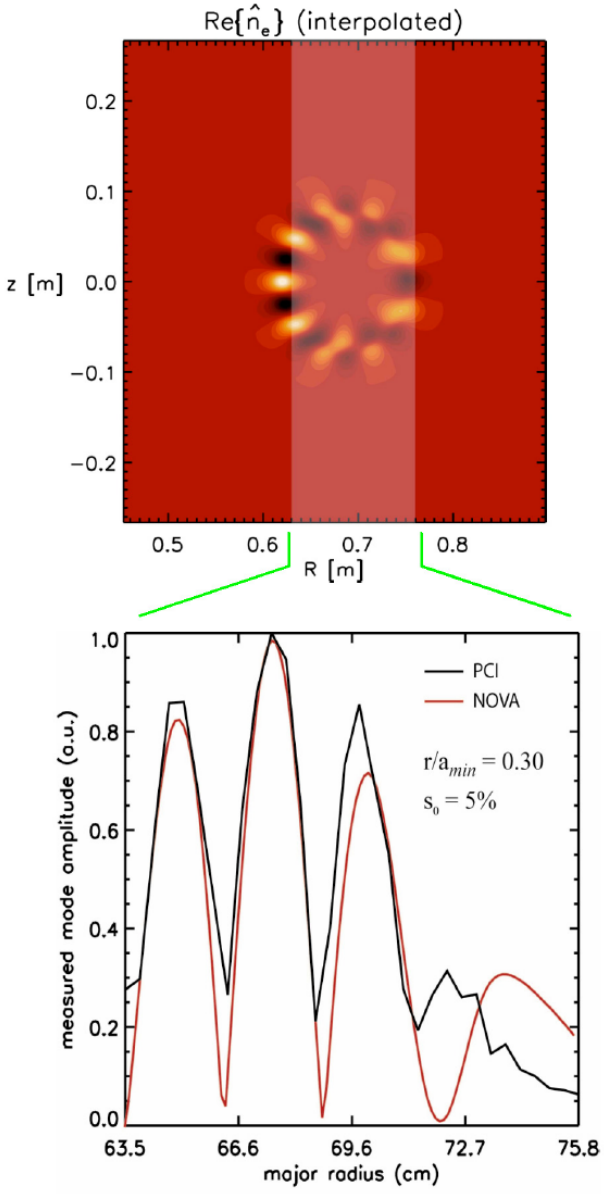
Combined NIMROD-KPRAD simulations shows progress in comparing with disruption mitigation experiment



During initial jet penetration, code reproduces large density increase for He jet; small spike at leading edge plus density drop for Ar jet

When MHD modes begin to destroy flux surfaces, radiated power ⇒ ~ GW

Synthetic PCI analysis of 2-D TAE mode by NOVA-K matches the PCI measurements

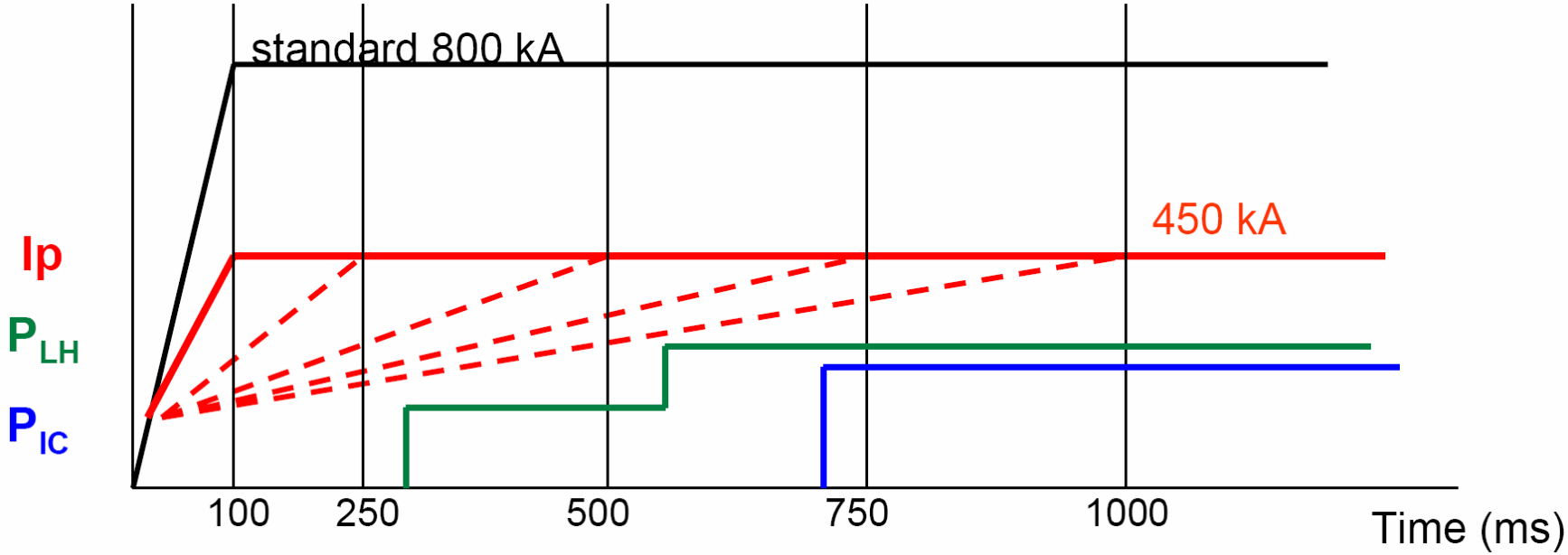


NOVA-K calculated 2-D mode structure is integrated along PCI beam lines and compared to measured PCI profile.

Multiply-peaked structure is a result of phase interference from the line integration of the signal.

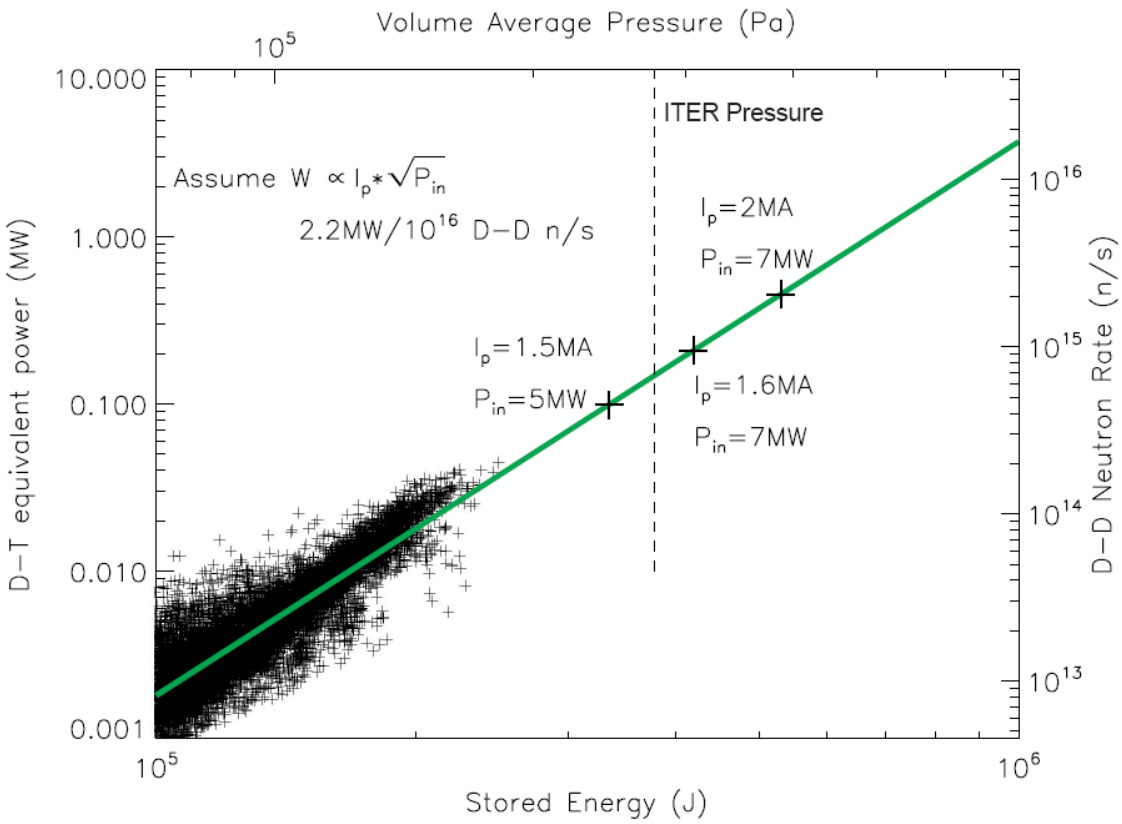
Lower Ip scenarios including ramp-up aim for higher NI fractions and long pulses

- **Other planned scenarios use reduced I_p (400-450 kA) to maximize non-inductive current fraction with available P_{LH}.**
  - 2006 expts achieved f_{BS}~22% in H-mode, without LHCD. Prior TRANSP modeling shows adding LHCD should amplify this.
- Explore adding LHCD in I_p ramp to see effect on j(r).
  - Likely different than other experiments due to short τ_{CR} on C-Mod.
- Both L-mode and H-mode regimes are of interest; also ITBs for greater f_{BS} (will not be time for all options in 2007).



Extend high performance plasmas at ITER field, shape, I/aB & β, integrating confinement, heating & particle control

- Operate at ITER field (5.3T), maximum power ($P_{ICRF} > 5MW$)
  - $f \approx 80$MHz, D(H) heating
  - high single pass absorption
- High elongation ($\kappa = 1.8$) ITER shape fills C-Mod vessel
- Increase current to $I_p = 1.6MA$ with $q_{95} \gtrsim 3$

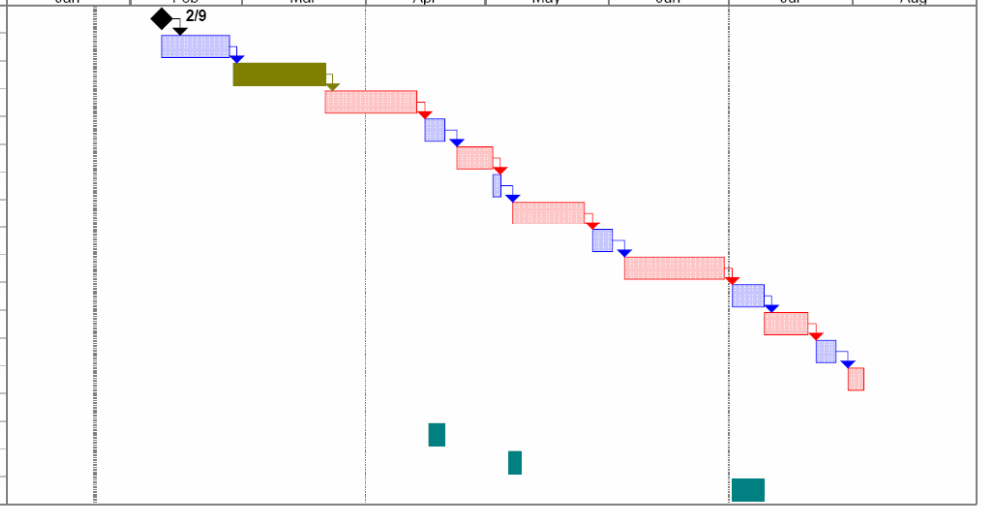


- Use cryo-pump for density control, lower collisionality
- Expanded parameter space for databases and extrapolation to ITER
- Demonstration of operation at ITER absolute pressure

Run schedule and run time allocation

Alcator C-Mod Schedule as of 01/23/2007

ID	Task Name	Duration	Start	Finish
1	pumpdown	0 days	Fri 2/9/07	Fri 2/9/07
2	bake/ecdc	17 days	Fri 2/9/07	Sun 2/25/07
3	plasma condition	14 days	Tue 2/27/07	Wed 3/21/07
4	plasma ops #1 (78 MHz)	14 days	Thu 3/22/07	Fri 4/13/07
5	maintenance	5 days	Mon 4/16/07	Fri 4/20/07
6	plasma ops #2 (reversed field)	6 days	Tue 4/24/07	Wed 5/2/07
7	maintenance	2 days	Thu 5/3/07	Fri 5/4/07
8	plasma ops #3 (78 MHz)	12 days	Tue 5/8/07	Fri 5/25/07
9	maintenance	5 days	Mon 5/28/07	Fri 6/1/07
10	plasma ops #4 (78 MHz)	16 days	Tue 6/5/07	Fri 6/29/07
11	maintenance	5 days	Mon 7/2/07	Mon 7/9/07
12	plasma ops #5 (50 MHz)	8 days	Tue 7/10/07	Fri 7/20/07
13	maintenance	5 days	Mon 7/23/07	Fri 7/27/07
14	plasma ops #6 (70 MHz)	4 days	Tue 7/31/07	Fri 8/3/07
15				
16	TTF	4 days	Tue 4/17/07	Fri 4/20/07
17	RF Conference	3 days	Mon 5/7/07	Wed 5/9/07
18	EPS	5 days	Mon 7/2/07	Mon 7/9/07



Initial Allocation (days)

Operations	6
Diagnostics	4
Divertor/Edge	6
Transport	10
MHD	6
Lower Hybrid	9
ICRF Physics	6
Integrated Scenarios (H-mode Baseline)	6
Integrated Scenarios (AT)	7
Total	**60**